THE EFFECT OF RED IMPORTED FIRE ANTS AND INVERTEBRATE ABUNDANCE ON NORTHERN BOBWHITE ABUNDANCE

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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August 2017

Major Subject: Wildlife and Fisheries Sciences

ABSTRACT

The northern bobwhite (*Colinus virginianus*; hereafter bobwhite) has experienced significant declines over the past decades. Few studies have documented the effects red imported fire ants (*Solenopsis invicta*; hereafter RIFA) have on bobwhites, however, further research is needed to address different aspects of RIFA and bobwhite interactions. RIFA will predate on invertebrates, an important food source for nesting bobwhites and chicks; evaluating the effect RIFA have on bobwhites and/or invertebrates will help determine if RIFA are contributing to the decline.

My study took place at the Attwater Prairie Chicken National Wildlife Refuge in Colorado and Austin counties, Texas. I had 3 study sites; 2 in Colorado County (treated for RIFA/with predator control and non-treated/with predator control) and 1 in Austin County (non-treated/without predator control). Two-thirds of the refuge in Colorado County was aerially treated with Extinguish Plus®, a highly attractive ant control substance. I sampled invertebrates and RIFA on all 3 sites and I also trapped bobwhites on the 2 sites in Colorado County using funnel traps. Both sexes were banded and females were fitted with a radio collar. I used ANOVA to determine differences in invertebrate numbers and biomass on the 3 sites. I found greater ($P < 0.001$) invertebrate biomass in the Colorado County/non-treated site compared to the other 2 sites and greater ($P = 0.015$) invertebrate numbers in the Austin County site compared to the Colorado County/non-treated site. I found significantly ($P < 0.001$) more RIFA in the Austin County site than the other 2 sites. I captured 349 bobwhites from March 2016 through May 2017. Bobwhite relative abundance for 2016 was 87 (95% CI = 47–108), 60 in treated and 27 in non-treated area; for 2017, bobwhite relative abundance was 53 (95% CI = 36–70), 43 in treated site and 10 in non-treated site. I rejected my hypothesis that I would find more bobwhites in areas with lower RIFA as well as in areas with greater invertebrate biomass and numbers. Therefore, it appears that treatment for RIFA had no effect on bobwhite abundance, however; major flooding on 18 April 2016 may have influence my results.

DEDICATION

This thesis is dedicated to my 3 wonderful boys; Jayden, Adriel, and Axel. No matter how much more difficult my journey became, from the start at a community college till the last word on this thesis, they were my greatest inspiration to continue through the rockiest of my paths to complete my educational goals. They have endured all the time I have put into my course work, research and writing this thesis; the play and fishing time I set aside to do my work; in the end, it will all be worth it. Being a first-generation college student, I believe I have set the stake high for my boys and I hope, with my example, the 3 will do the same or perhaps even better than I did. I love you boys!

Also, I dedicate this thesis to Cati, for believing in me and the wonderful support throughout those years. Finalmente, para mis padres, Clemente y Carolina. Mi pa, por enseñarme amar la naturaleza, que desde pequeño me llevava a pezcar y a la cazeria. Mi ma, por enseñarme que nunca ay que darse por vecidos sin importer los obstaculos; a los dos, sin estas calidades no lo hubiera hecho. Gracias!

ACKNOWLEDGMENTS

First, I would like to thank Dr. Jim Cathey for funding this project. Funding was provided through the Reversing the Quail Decline in Texas Initiative and the Upland Game Bird Stamp Fund based on a collaborative effort between Texas Parks and Wildlife Department and Texas A&M AgriLife Extension.

I would like to thank everyone who helped in one way or another with the project; Mike Keenan, Corey Pursell, Trey Johnson, Zach Johnson, and a few other undergraduates that helped in the field as well as with the invertebrate and ant sorting. My committee members, Dr. Fred Smeins and Dr. Roel Lopez, thank you for your support and feedback. Lastly, I couldn't thank enough, Dr. Nova Silvy. I couldn't say how much I've learned from you; in the field, those talks about quail, prairie chickens and other wildlife. All that said, one thing was certain, I was never out in the field with an empty stomach. Thanks for helping me in every way possible.

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CHAPTER I

INTRODUCTION

The red imported fire ant (RIFA, *Solenopsis invicta*) is thought to have been introduced into Mobile, Alabama in the early 1920s (Buren et al. 1974). By the late 1950s, the RIFA had reached Texas, where it continued to spread further westward throughout Texas (Callcott and Collins 1993). Since the 1960s, the northern bobwhite (*Colinus virginianus*; hereafter bobwhite) has had a continuous population decline over much of their range in the southeastern United States, including Texas (Rollins and Carroll 2001). Extensive research has been done to address this issue, which has led to several different probable causes including habitat fragmentation (Guthery 2000, Burger 2001), woody plant encroachment (Welch et al. 2004), predation (Rollins and Carroll 2001) as well as other possible causes for this decline. Some research has been done on the effects of RIFA on bobwhites (Allen et al. 1995), but further research is needed to identify specific problems RIFA have on bobwhite populations. The nindirect effect of RIFA on invertebrate abundances, an important food source for breeding and newly hatched bobwhites, requires study to determine if RIFA have an indirect negative effect on bobwhites.

The nutritional demand for non-breeding bobwhites consists of 90% seeds, grain, and fruit; the other 10% are insects (Brennan 2007). During the breeding season (spring and summer), the nutritional demand (e.g., protein and calcium) for females increases, making invertebrates a larger part of their diets (Brennan 2007). Insects also comprise a large portion of growing chicks' diet due to their high-energy demand required for growth. If RIFA are found to decrease invertebrate abundance, it would support the hypothesis that breeding quail and chicks are forced to eat less food or less nutritional food sources leading to the lack of necessary proteins and calcium needed for egg-laying for females and early growth development for chicks.

Livestock grazing and prescribed burning can influence invertebrate and RIFA abundance on grasslands. Debano (2006) noted insect abundance was lower in grazed areas than in non-grazed areas. Vegetation height and density also is a factor to consider when evaluating invertebrate abundance. Prescribed burning can have an immediate effect on invertebrate abundance during the first 1–2 months after a burn (Swengel 2001). Together, these grazing and prescribed burns may make a difference in determining what effect RIFA and/or invertebrate are having on bobwhites.

RESEARCH OBJECTIVES

Research objectives for my study were to evaluate the effects of: (1) Extinguish Plus® treatment on RIFA abundance, (2) RIFA treatment on invertebrate abundance, and (3) invertebrate and RIFA abundance on bobwhite abundance.

STUDY AREA

Research was conducted at the Attwater Prairie Chicken National Wildlife Refuge (APCNWR) located about 100 km west of Houston, Texas in Colorado and Austin counties. A previous study (Caldwell 2015) on APCNWR included only the main refuge located in Colorado County; my study also includes the Austin County portion of the refuge and was used as a control site for the effects of predator control on RIFA abundance. In theory, if mammalian predators are controlled, then there should be more rats, mice, and rabbit babies for RIFA to use as a food source. This mammalian food source (altricial young in nests) should be more assessable to RIFA than arthropods that could avoid RIFA by moving, flying, or escaping up tall vegetation. The Austin County site had no predator control and was not treated for RIFA (hereafter, Austin County site), whereas the main refuge (Colorado County) had predator control throughout and 75% of the area was treated (hereafter; main refuge/treated) and 25% was not treated (hereafter; main refuge/non-treated) for RIFA with Extinguish Plus®, a highly attractive ant control substance. RIFA treatment was applied at the APCNWR to allow increased survival and recruitment for the endangered Attwater's prairie chicken (*Tympanuchus cupido attwateri*). Since bobwhites share similar habitats with the prairie chickens, it allowed me the opportunity to determine if treatment with Extinguish Plus® also would increase bobwhite survival. Extinguish Plus® is an adulticide (Hydramethylnon) and has a long-lasting insect growth regulator (S)-mesophrene which works by sterilizing the queen to prevent further reproduction in the ant colony (www.extinguishfireants.com). Extinguish Plus® application is safe for horses and cattle, so it does not require any withdraw periods and it begins killing fire ants immediately after ingestion (www.extinguishfireants.com). Extinguish Plus® was applied yearly at 0.68 kg/0.40 ha to 3,035 ha of the 4,047-ha refuge. Annual aerial applications were conducted yearly in areas occupied by Attwater's prairie chickens;

75% of the refuge was treated for RIFA and 25% was not treated for RIFA (Terry Rossignol; personal communication). Areas treated with Extinguish Plus® were noted as treated areas and the areas not treated with Extinguish Plus® were noted as non-treated areas. During 2013, areas shaded in green (Fig. 1.1) were treated for RIFA, areas shaded in green and light color (Fig. 1.1) were treated during 2014 and 2015. For 2016 and 2017, areas shaded in yellow and blue were treated for RIFA (Fig. 1.2).

The refuge is located in the Gulf Coast Prairies and Marshes Ecoregion of Texas. The average annual rainfall for Sealy, Texas, which is 22 km northeast of the refuge, is 101 cm per year (www.usclimatedata.com). The highest monthly rainfall was recorded in April 2016 at 41 cm of which 31 cm fell on 18 April 2016 (Fig. 1.3). Due to this heavy rainfall occurrence on 18 April 2016, the San Bernard River, which forms the east boundary of the refuge, caused major flooding to the refuge (Fig. 1.4). Other areas of the refuge were flooded due to the high rainfall event and not by the river flooding.

The APCNWR has had a variety of wildlife management and farming practices throughout and in certain portions of the refuge. Prescribed burning is conducted yearly to different areas of the refuge as needed (3-5 year burns), but mainly in the treated areas (Fig. 1.1). Cattle grazing is also a management approach throughout the refuge, more recently, fences have been taken down to allow cattle to enter and graze the adjacent pastures throughout the refuge. Also, the southern portion of the non-treated area has been historically rice fields. Rice fields are leveled out to allow water to be trapped and stand in the fields. There are also more compact soils in this part of the refuge which prevent water from easily draining after heavy rains; these two factors make this area more prone to flooding and standing water over long periods of time. The eastern part of the main refuge/non-treated area along the river (Fig. 1.2) consists of mostly sandy, well drained soils. This coarse, sandy soil characteristic drains fairly well compared to the rest of the refuge which is mostly compact, clay-pan and loamy soils.

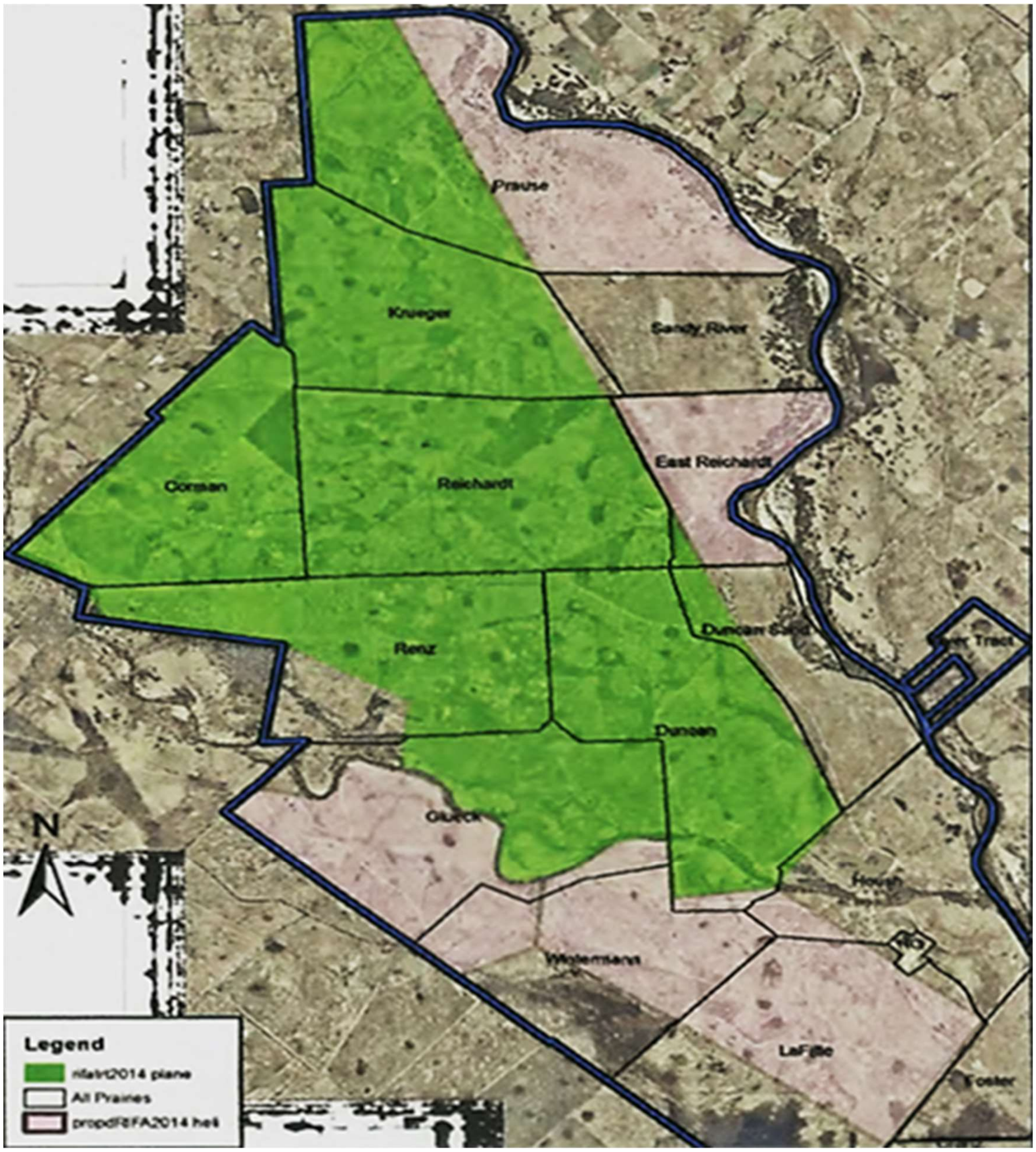


Figure 1.1: Areas on the Attwater Prairie Chicken National Wildlife Refuge (APCNWR) in Colorado County treated with Extinguish Plus® during 2013, 2014, and 2015 (Rebeca Chester, Biologist, APCNWR, Eagle Lake, Texas).

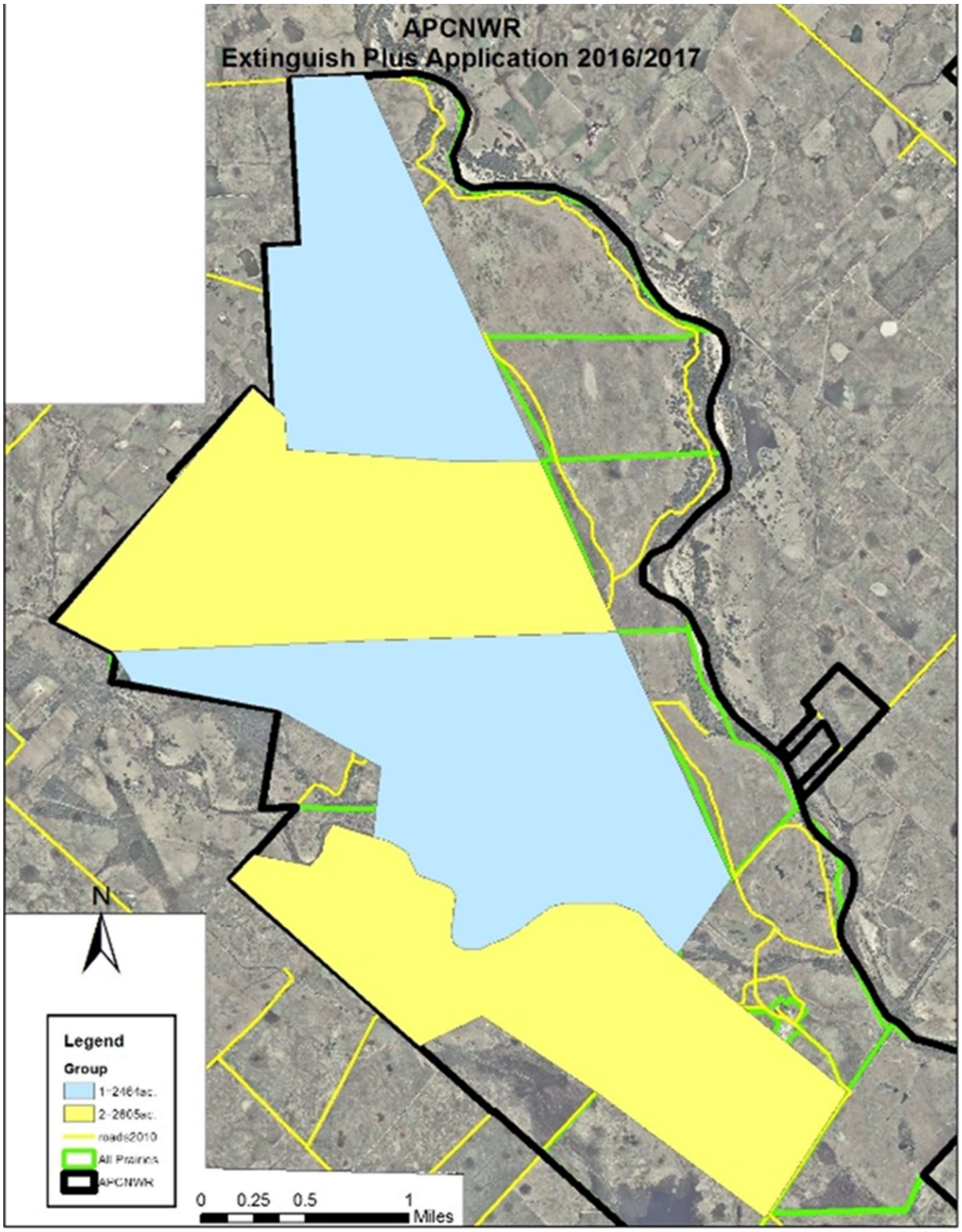


Figure 1.2: Areas on the Attwater Prairie Chicken National Wildlife Refuge (APCNWR) in Colorado County treated with Extinguish Plus® during 2016 and 2017 (Rebeca Chester, Biologist, APCNWR, Eagle Lake, Texas).

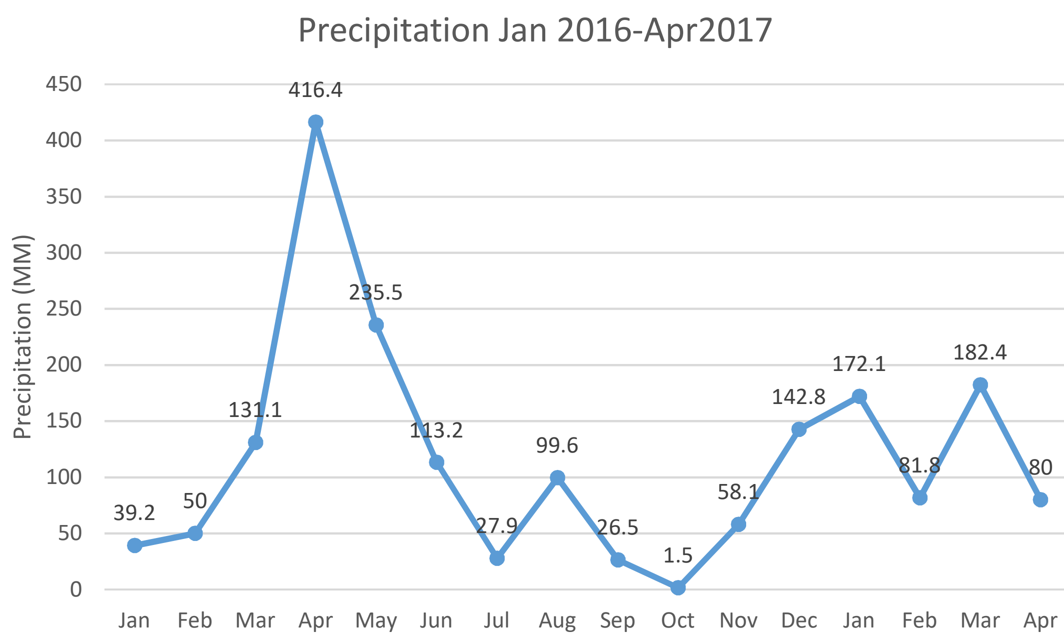


Figure 1.3: Monthly precipitation totals for Sealy, Texas (22 km east of the refuge) for January 2016 through April 2017 (www.usclimatedata.com).

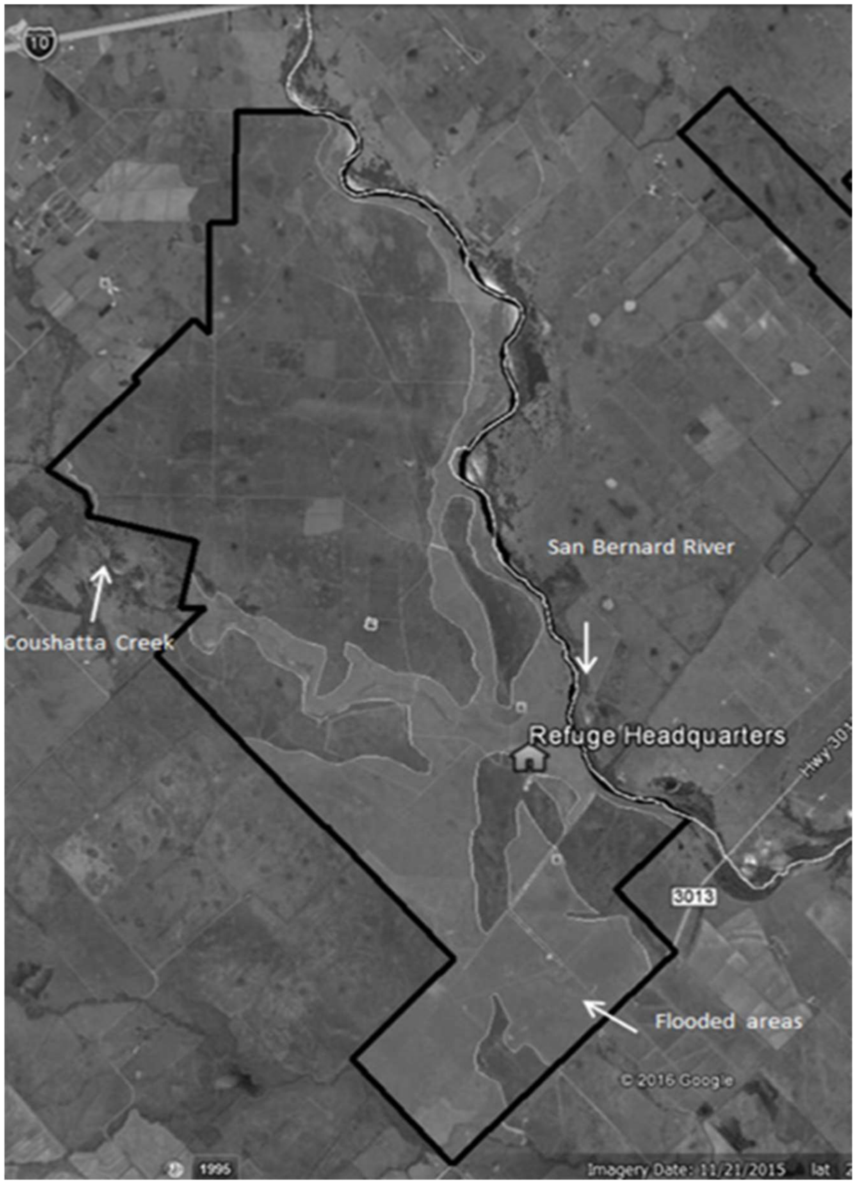
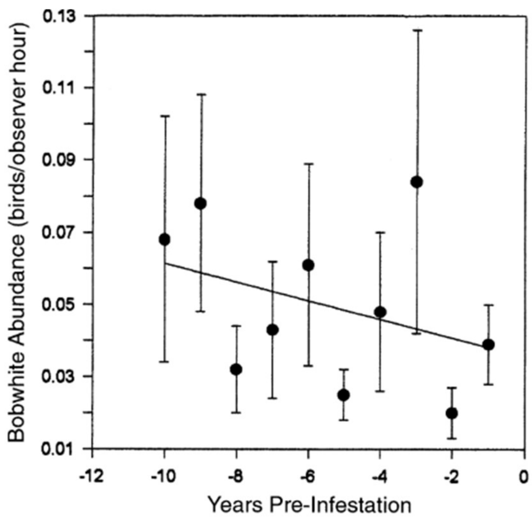


Figure 1.4: Areas of Attwater Prairie Chicken National Wildlife Refuge (APCNWR), Colorado County, Texas, flooded by heavy rains on 18 April 2016. (Note: lighter shade is the flooded areas; Map generated by John Magera, Deputy Refuge Manager, APCNWR, based on his personal observations of the flooding).

CHAPTER II

THE EFFECT OF EXTINGUISH PLUS® TREATMENT ON RIFA

The red imported fire ants (RIFA, *Solenopsis invicta*) have been known to prey on northern bobwhite (*Colinus virginianus*; hereafter bobwhite) and to negatively affect their densities (Allen et al. 1995). Historical accounts indicate that since the infestation of RIFA, beginning in Mobile, Alabama, bobwhite populations began to decline as well. According to Allen et al. (1995), before RIFA infestation in 15 Texas counties there was no significant bobwhite population decline (Fig. 2.1). After RIFA infestation, a significant bobwhite population abundance decline was observed in all 15 counties (Fig. 2.2).



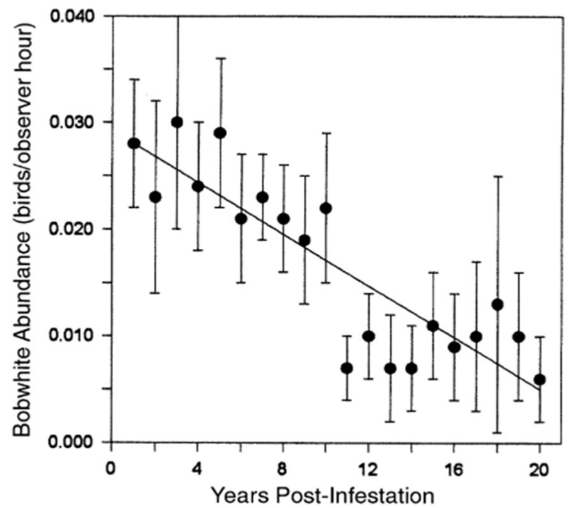


Fig. 2.1: Bobwhite abundance in 15 counties in Texas pre-RIFA infestation (abundance based on Christmas Bird Count data; reprinted from Allen et al. 1995)

Fig. 2.2: Bobwhite abundance in 15 counties in Texas post-RIFA infestation (abundance based on Christmas Bird Count data; reprinted from Allen et al. 1995).

This suggested RIFA was a potential cause for the bobwhite decline in Texas. Direct observational studies also have indicated RIFA have affected bobwhite chick as well as other shorebird nestling survival (Drees 1994). Giuliano et al. (1996*a*) found bobwhite chick survival to be reduced by exposure to 50 RIFA for 60 seconds and 200 RIFA at 15 seconds. This indicates that bobwhite chick survival could be affected in a field infested with RIFA, especially during and immediately after hatching when bobwhite chicks are most vulnerable to RIFA predation. Mueller et al. (1999) found bobwhite nests treated (60 x 60 m area centered on each nest) with Amdro (American Cyanamid Company, Wayne, New Jersey) did not differ significantly in hatch success from non-treated nests. However, they observed greater mortality of bobwhite chicks by RIFA once they left the treated nest sites into non-treated areas. While Mueller et al. (1999) did not find differences in hatching success for small areas treated around nests, it is important to determine if large-scale RIFA treatment would find differences in hatching success between treated and non-treated areas. RIFA may be affecting invertebrate abundance (an important food source for bobwhite chicks) and differences in subsequent bobwhite chick survival in treated and non-treated areas. Since the treatment by Mueller et al. (1999) was centered on a 60 x 60-m area centered on each nest, chicks shortly after hatching in treated nests were led out of those treated areas, exposing them to RIFA as were chicks from non-treated nests. Using a large-scale treatment area would provide better information of the effects of RIFA in treated versus non-treated areas. The objective of my study was to evaluate the effects of Extinguish Plus® treatment on RIFA abundance. My hypothesis was that areas treated with Extinguish Plus® would have significantly lower RIFA abundance then the non-treated sites.

STUDY AREA

Research was conducted at the Attwater Prairie Chicken National Wildlife Refuge (APCNWR) located about 100 km west of Houston, Texas in Colorado and Austin counties. Caldwell (2015) included only the main refuge located in Colorado County; whereas my study included the Austin County portion of the refuge and was used as a control site for the effects of predator control on RIFA abundance. In theory, if mammalian predators are controlled, then there should be more rats, mice, and rabbit babies for RIFA to use as a food source. This mammalian food source (altrical young in nests) should be more assessable to RIFA than arthropods that could avoid RIFA by moving, flying, or escaping up tall vegetation. The portion located in Austin County had no predator control and was not treated for RIFA (hereafter; Austin County site), whereas the main refuge (Colorado County) had predator control throughout and 75% of the area was treated (hereafter; main refuge/treated) and 25% was not treated (hereafter; main refuge/non-treated) for RIFA with Extinguish Plus®, a highly attractive ant control substance. RIFA treatment was applied at the APCNWR to allow increased survival and recruitment for the endangered Attwater's prairie chicken (*Tympanuchus cupido attwateri*). Since bobwhites share similar habitats with the prairie chickens, it allowed me the opportunity to determine if treatment with Extinguish Plus® also would increase bobwhite survival. Extinguish Plus® has an adulticide (Hydramethylnon), a long-lasting insect growth regulator (S)-mesophrene which works by sterilizing the queen to prevent further reproduction in the ant colony (www.extinguishfireants.com). Extinguish Plus® application is safe for horses and cattle, so it does not require any withdraw periods and it begins killing fire ants immediately after ingestion (www.extinguishfireants.com). Extinguish Plus® was applied twice yearly in early spring and late fall at 0.68 kg/0.40 ha to 3,035 ha of the 4,047-ha refuge. Annual aerial applications are conducted each year in areas occupied by Attwater's prairie chickens; 75% of the refuge was treated for RIFA and 25% was not treated for RIFA (Terry Rossignol; Refuge Manager, APCNWR, personal communication). Areas treated with Extinguish Plus® were noted as treated areas and the areas not treated with Extinguish Plus® were noted as non-treated areas.

METHODS

RIFA sampling sites were selected randomly throughout the refuge, but avoided quail baiting sites as RIFA are attracted to the quail bait which could possibly influence RIFA estimates for those areas. Twenty-six sampling sites were randomly selected at the main refuge (Colorado County) and 9 sites were selected at the Austin County portion of the refuge for each month that collections were made. I tried to collect RIFA abundance data on the same day of the month each month to be consistent, but weather and other factors sometimes interfered with my ability to do so. Two crews were organized to collect RIFA samples; one crew placed baited petri dishes at each site while the other crew retrieved them after 20 minutes of exposure. Two baited petri dishes were placed approximately 3 m apart at each site, one containing dry cat food (Meow Mix Tender Centers® dry pelleted cat food, Big Heart Pet Brands, San Francisco, California) and one dish containing hotdog slices. The 2 petri dishes were placed at exactly the same time; the time was noted and texted to the other crew members. The second crew members waited 20 minutes before picking up the dishes at each site and immediately, covered them with the lid and sealed them with duct tape to prevent any ant escapes. Petri dishes were then placed in a cooler with ice and later frozen. At the lab, an ant identification key (Cook et al. 2014) was used to identify ants to species. The number of RIFA per petri dish by site was recorded separately as were all other ant species. An Analysis of Variance (ANOVA) was used to compare the means at the 3 different sites (main refuge/treated, main refuge/non-treated, and Austin County site) to see if treatment with Extinguish Plus® was effective at reducing RIFA from the treated sites. A Tukey-Kramer HSD test was used to compare the differences within the 3 means to see if site(s) differ from one another.

RESULTS

A number of native ant species also were collected in addition to the RIFA. Other ant species collected at bait sites included crazy ants (*Nylanderia terricola*), leaf cutter ants (*Atta* or *Acromyrmex spp*.), pyramid ants (*Dorymyrmex pyramicus*), and harvester ants (*Pogonomyrmex spp.*). In the 2016 RIFA collection, 3,068 RIFA ($\bar{x}$ = 23.6 per sample) of 5,326 total ants (57.6% RIFA) were collected in the main refuge/

treated site (Table 2.1); 1,672 RIFA ($\bar{x}$ = 12.9 per sample) of 2,873 total ants (58.2% RIFA) were collected in the main refuge/non-treated site (Table 2.1); and 11,065 RIFA ($\bar{x}$ = 250.6 per sample) of 11,657 total ants (94.9% RIFA) were collected on Austin County site (Table 2.2). An ANOVA found a significant difference (F = 77.59, P = 0.0001) between the 3 treatment types. A Tukey-Kramer HSD test revealed significantly (P < 0.0001) more RIFA in the Austin County site than in the main refuge/treated site. In addition, significantly (P < 0.0001) more RIFA were found in the Austin County site than in the main refuge/non-treated sites. There was a slightly significant (P = 0.0497) larger number of RIFA at the main refuge/treated site than the main refuge/non-treated site.

In 2017, I collected RIFA only during April and May. Only 10 ($\bar{x}$ = 0.2 RIFA per sample; Table 2.1) RIFA were collected at the treated site, 184 ($\bar{x}$ = 3.5 RIFA per sample; Table 2.1) RIFA were collected on the main refuge/non-treated site, and 218 ($\bar{x}$ = 12.1 RIFA per sample; Table 2.2) RIFA were collected at the Austin County site. An ANOVA found a difference (F = 68.97, P < 0.001) between the 3 sites. A Tukey-Kramer HSD test found significantly fewer RIFA in the main refuge/treated site than the Austin County site (P < 0.001) as well as the main refuge/non-treated site (P < 0.001).

The total number of ants collected for April 2016 through May 2017 are as follow: main refuge/treated (Table 2.1), 3,078 RIFA ($\bar{x}$ = 16.9 per sample) of 5,680 total ants (54.2% RIFA); main refuge/non-treated (Table 2.1), 1,856 RIFA ($\bar{x}$ = 10.2 per sample) of 3,178 total ants (58.4% RIFA); and Austin County (Table 2.2), 11,283 RIFA ($\bar{x}$ = 182.0 per sample) of 12,865 total ants (87.7% RIFA). For the pooled RIFA collections (April 2016–May 2017) of the 3 sites there was a significant (F = 60.38, P < 0.001) difference among the 3 treatment sites. A Tukey-Kramer HSD test found significantly (P < 0.001) greater numbers of RIFA in the Austin County site than in the main refuge/non-treated site, and a significantly (P < 0.001) greater number of RIFA in the Austin County site than in the main refuge/treated site; no difference (P = 0.166) was found between the main refuge treated and non-treated sites.

For the 2016 collection, August has the greatest number of RIFA collected for both sites of the main refuge (Colorado County), treated (2,256 RIFA) and non-treated (1,151 RIFA; Table 2.2). For the Austin County site, June has the greatest number of RIFA collected with 5,202 RIFA (Table 2.2). There appeared to be a large increase in RIFA at the Austin County site beginning June 2016 ($\bar{x}$ = 578 RIFA per sample) and numbers remained high through August (Table 2.2). In the main refuge treated and non-treated sites, I saw a large increase of RIFA ($\bar{x}$ = 86.77 and $\bar{x}$ = 44.27 per site, respectively) in August 2016 (Table 2.1).

Table 2.1: Total ants and total RIFA (sample size in parentheses) collected each month by treatment/non-treatment on Attwater Prairie Chicken National Wildlife Refuge, Colorado County, Texas, 2016–2017.

Month/year	Treated total ants	Non-treated total ants	Treated RIFA	Non-treated RIFA
April 2016	454(26)	530(26)	299(26)	158(26)
May 2016	138(26)	766(26)	64(26)	286(26)
June 2016	517(26)	157(26)	280(26)	65(26)
July 2016	246(26)	166(26)	169(26)	12(26)
August 2016	3,971(26)	1,254(26)	2,256(26)	1,151(26)
Total 2016	5,326(130)	2,873(130)	3,068(130)	1,672(130)
April 2017	118(26)	107(26)	6(26)	43(26)
May 2017	236(26)	198(26)	4(26)	141(26)
Total 2017	354(52)	305(52)	10 (52)	184(52)
Grand total	5680(182)	3,178(182)	3,078(182)	1,856(182)

Table 2.2: Total ants, total RIFA, and sample size collected each month on the no treatment and no predator control site on Attwater Prairie Chicken National Wildlife Refuge, Austin County, Texas, 2016–2017.

Month/year	Total ants	RIFA	Sample size
April 2016	306	304	8
May 2016	76	20	9
June 2016	5,202	5,025	9
July 2016	2,771	2,375	9
August 2016	3,302	3,302	9
Total 2016	11,657	11,065	44
April 2017	795	37	9
May 2017	413	181	9
Total 2017	1,208	218	18
Grand total	12,865	11,283	62

DISCUSSION

The 2015 Extinguish Plus® treatment appeared to have no effect on RIFA numbers during 2016. Results differed from my hypothesis that RIFA numbers would be less in the treated areas than in the non-treated areas; instead the opposite occurred; there was 183.5% more RIFA in the treated area compared to the non-treated area of the main refuge. Flooding on the main refuge/non-treated site apparently reduce RIFA populations, whereas the main refuge/treated site probably accumulated rafts of RIFA being transported downstream in the San Barnard River from population upstream of the refuge. During floods, RIFA are known to form rafts of worker ants; with the queen, safely on top of the raft, and float until they reach higher sites (Virginia Cooperative Extensions 2010). The movement of RIFA onto treated sites (where less flooding occurred) could have increased numbers of RIFA on the treatment area. It is not likely that the RIFA treatment got washed away by the flood as the RIFA treatment was applied well before the flood and RIFA most likely gathered the bait long before the flood happened.

The Extinguish Plus® treatment in fall 2016 and spring 2017 was successful at decreasing RIFA in the treated area for the 2017 RIFA collection. Although I only collected RIFA during April and May, I did find only 6 and 4 RIFA were collected for April and May, respectively; therefore, I was able to conclude the treatment did reduce RIFA significantly. In absence of extreme weather conditions Extinguish Plus® treatment does reduce RIFA numbers when applied appropriately. RIFA numbers were much lower throughout the 3 sites in April and May 2017 compared to 2014–2016. It is possible the low temperatures observed in January 2017 may have killed many of the RIFA; the lowest recorded temperatures were -6.7° C for 7 January 2017 and -6.1° C for 8 January 2017 (www.usclimatedata.com). These low temperatures could have reduced the number of RIFA for the months of April and May.

Caldwell (2015) collected data on RIFA abundance on my study areas during springs 2014 and 2015 and found a significant reduction of RIFA (73.4%) on treated sites compared to non-treated sites. Caldwell (2015) collected 1,423 RIFA (n = 183) in the treated area and 6,785 RIFA (n = 161) in the non-treated area; my numbers were different, the non-treatment area showed less RIFA than in the treated area. This, also, indicated Extinguish Plus® treatment could be affected by extreme variables such as heavy rainfall. Because Caldwell (2015) did not collect RIFA in Austin County, I did not have a comparison for the Austin County study area. At the Austin County site, I did find a significantly larger number of RIFA when compared to the treated and non-treated sites in Colorado County. It is important to note the refuge has been treated every year since at least 2011 (Morrow et al. 2015 and M. Morrow, APCNWR, personal communication), with a continuous application of the treatment, one would expect the main refuge to contain fewer RIFA than the Austin County site. In conclusion, the results supported my hypothesis that an untreated area would have more RIFA compared to a treated area.

CHAPTER III

THE EFFECT OF RIFA ABUNDANCE ON INVERTEBRATE ABUNDANCE

Insects are an important food source for nesting and growing bobwhites. The nutritional demand for non-breeding northern bobwhites (*Colinus virginianus*; hereafter bobwhite) consists of 90% seeds, grain, and fruit; the other 10% are insects (Brennan 2007). During the breeding season (spring and summer), the nutritional demand (i.e., protein and calcium) for female bobwhites increases, making invertebrates a larger part of their diets (Brennan 2007). Laying eggs comes at a high cost; high protein levels are required for the egg contents and high calcium is required for the egg shell (Larson et al. 2010). The optimal protein requirement for females is typically around 23% (Nestler et. al. 1944, Giuliano et al. 1996*b*) in order to maximize the number of eggs laid; females tend to lay fewer eggs as protein levels decrease (Larson et al. 2010). The calcium requirement for female bobwhite is typically around 2.3%. Both protein and calcium needs can be met by consuming insects. Protein is responsible for the development of muscle, feathers, eggs as well as other important physiological processes in quail (Dozier and Bramwell 2002). Robel et al. (1974) analyzing food content in bobwhite crops, found larger proportions of insect matter in quail crops that were collected further from food plots then quail crops collected near food plots. Most of the insect matter consumed was in months of high insect abundance (late spring, late fall). Thus, in absence of food plots (seeds), insects become more important to bobwhites.

Insects also comprise a large portion of growing chicks' diet due to high energy demand required for growth. The direct correlation between chick survival and insect abundance noted by Doxon and Carroll (2010) indicate the importance of evaluating red imported fire ant (RIFA, *Solenopsis invicta*) abundance in relation to their effect on bobwhite abundance. If RIFA are found to decrease invertebrate abundance, it would support the idea that less food or less nutritional food sources are available to breeding quail and chicks thereby leading to the lack of necessary proteins and calcium needed for egg-laying for females and growth development of chicks. The objective of my study was to evaluate the effects of RIFA abundance on invertebrate abundance. The hypothesis for this portion of my study is areas with RIFA treatment will have larger invertebrate biomass and numbers than non-treated areas.

STUDY AREA

Research was conducted at the Attwater Prairie Chicken National Wildlife Refuge (APCNWR) located about 100 km west of Houston, Texas in Colorado and Austin counties. Caldwell (2015) conducting a previous study at the APCNWR included only the main refuge located in Colorado County; for my study, I also included the Austin County portion of the refuge which had no predator control and was not treated for RIFA. The main refuge (Colorado County) had predator control throughout and 75% of the area was treated (hereafter; main refuge/treated) and 25% was not treated (hereafter; main refuge/non-treated) for RIFA with Extinguish Plus®, a highly attractive ant control substance. RIFA treatment was applied at the APCNWR to allow increased survival and recruitment for the endangered Attwater's prairie chicken (*Tympanuchus cupido attwateri*). Since bobwhites share similar habitats with the prairie chickens, it allowed me the opportunity to determine if treatment with Extinguish Plus® also would increase northern bobwhite survival. Extinguish Plus® has an adulticide (Hydramethylnon), a long-lasting insect growth regulator (S)-mesophrene which works by sterilizing the queen to prevent further reproduction in the ant colony (http://www.extinguishfireants.com). Extinguish Plus® application is safe for horses and cattle, so it does not require any withdraw periods and it begins killing fire ants immediately after ingestion (http://www.extinguishfireants.com). Extinguish Plus® is applied yearly at 0.68 kg/0.40 ha to 3,035 ha of the 4,047-ha refuge. Annual aerial applications were conducted yearly in areas occupied by Attwater's prairie chicken; 75% of the refuge was treated for RIFA and 25% was not treated for RIFA (Terry Rossignol; Refuge Manager, APCNWR, personal communication). Areas treated with Extinguish Plus® were noted as treated areas and the areas not treated with Extinguish Plus® are noted as non-treated areas.

METHODS

From March through August, invertebrate samples were collected once per month using sweep nets (35-cm aperture; Forestry Suppliers, Jackson, Mississippi). Sites where RIFA also were collected were used to sample invertebrates. Twenty-six sampling sites were selected at random each month throughout the main refuge

(Colorado County) and 9 sites were selected at the Austin County portion of the refuge. Efforts were made to collect invertebrates on the same day of the month each month, however, rain and other factors (flooding) interfered with our ability to collect on certain dates making our collection dates differ for some months. Two crews were used each moth with the first crew setting RIFA petri dishes with ant baits collecting invertebrate samples (sweep netting). Once petri dishes were placed, the 2 persons comprising the first crew each went in a random direction starting at the ant collection station to sweep for invertebrates. After the 25th sweep, the sweep net was secured to keep invertebrates from escaping. Sweep net contents were then emptied into a zip-lock bag, sealed, and placed in a cooler with ice. Each bag was dated and the site number was noted with a sharpie marker and placed in a freezer until they could be processed. When time permitted, insects were sorted to Order, the biomass and number were collected and ANOVA was used to compare the means for the 3 treatment sites. If I had a significant difference in the means using an ANOVA, I used the Tukey-Kramer HSD test to determine which means were different.

RESULTS

Individual invertebrates collected during April and May were usually smaller than those collected during later months (June–August). Major insect Orders collected were Hemiptera, Diptera, Orthoptera, Coleoptera as well as spiders (Fig. 3.1 and 3.2). The mean biomass for the 3 treatment sites for 2016 were as follow (Table 3.1): main refuge/treated ($\bar{x}$ = 0.135, *SD* = 0.130), main refuge/non-treated ($\bar{x}$ = 0.365, *SD* = 0.394), and Austin County ($\bar{x}$ = 0.138, *SD*= 0.158). The mean invertebrate numbers for 2016 were as follow (Table 3.1): main refuge/treated ($\bar{x}$ = 16.5, *SD* = 9.9, *n* = 65), main refuge/non-treated ($\bar{x}$ = 14.1, *SD* = 7.8, *n* = 65), and Austin County ($\bar{x}$ = 20.8, *SD* = 26.9, *n* = 44). In 2016, there was a significant difference in the invertebrate biomass (F = 40.84, $P < 0.001$) among the 3 treatments. A Tukey-Kramer HSD test indicated a significantly ($P < 0.001$) greater invertebrate biomass on the main refuge/non-treated than the Austin County site; a significantly ($P < 0.001$) greater invertebrate biomass in the main refuge/non-treated site than in the main refuge/treated site. For invertebrate numbers, a significant (F = 3.96, P = 0.021) difference was found between the 3 treatments. A Tukey-Kramer HSD test revealed significantly (P = 0.015) more invertebrates in the Austin County site than in the main refuge/non-treated site; no significant difference was found between the Austin County site and the main refuge/treated site (P = 0.170) as well as the main refuge/treated site and the main refuge/non-treated (P = 0.508).

The mean biomass for April 2017 invertebrates were (Table 3.1): main refuge/treated ($\bar{x}$ = 0.079, *SD* = 0.037, *n* = 13), main refuge/non-treated ($\bar{x}$ = 0.070, *SD* = 0.051, *n* = 13), and Austin County ($\bar{x}$ = 0.138, *SD* = 0.113, *n* = 9); the mean invertebrate numbers were (Table 3.1): main refuge/treated ($\bar{x}$ = 37, *SD* = 17.9, *n* = 13), main refuge/non-treated ($\bar{x}$ = 27.6, *SD* = 18.4, *n* = 13), and Austin County ($\bar{x}$ = 66.7, *SD* = 64.1, *n* = 9).

Table 3.1: Mean and standard deviation (SD) biomass (grams) and numbers of invertebrates by month in treated and non-treated areas on Attwater Prairie Chicken National Wildlife Refuge, Colorado and Austin counties, Texas, 2016 and 2017

Year 2016	**Main refuge/treated**				**Main refuge/ non-treated**				**Austin County**		
Month	x̄	SD	N		x̄	SD	N		x̄	SD	N
April 2016											
Biomass	0.020	0.025	13		0.033	0.023	13		0.048	0.053	8
Numbers	14.8	12.8	13		15.3	8.6	13		68.4	33.7	8
May 2016											
Biomass	0.151	0.077	13		0.192	0.139	13		0.067	0.044	9
Numbers	24.0	7.7	13		17.8	9.1	13		14.6	6.2	9
June 2016											
Biomass	0.161	0.116	13		0.303	0.308	13		0.165	0.098	9
Numbers	22.7	8.4	13		18.3	5.4	13		13.2	4.5	9
July 2016											
Biomass	0.222	0.178	13		0.616	0.673	13		0.098	0.114	9
Numbers	11.1	2.7	13		10.8	6.5	13		6.6	2.1	9
August 2016											
Biomass	0.121	0.122	13		0.386	0.390	13		0.158	0.138	9
Numbers	9.8	6.1	13		8.2	3.7	13		6.6	2.7	9
Overall 2016											
Biomass	0.135	0.130	65		0.365	0.394	65		0.107	0.104	4
Numbers	16.5	9.9	65		14.1	7.8	65		20.8	26.9	4
											4
											4
April 2017											
Biomass	0.079	0.037	13		0.070	0.051	13		0.138	0.113	9
Numbers	37	17.9	13		27.6	18.4	13		66.7	64.1	9

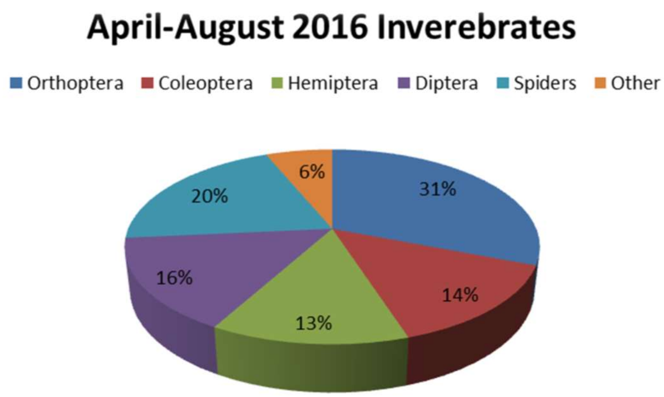


Figure 3.1: Invertebrate proportions by Order collected in 2016 at Attwater Prairie Chicken National Wildlife Refuge, Colorado and Austin counties, Texas.

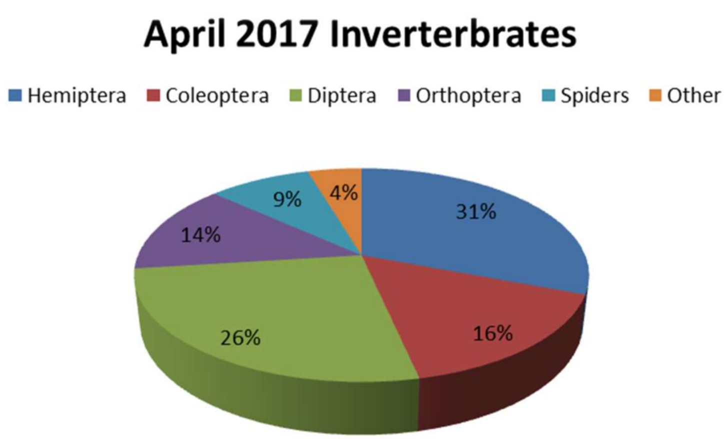


Figure 3.2: Invertebrate proportions by Order collected in April 2017 at Attwater Prairie Chicken National Wildlife Refuge, Austin and Colorado counties, Texas.

DISCUSSION

I expected to find more invertebrate numbers and biomass on the RIFA treatment site compared to the other 2 treatment sites. However, the floods in April 2016 appeared to have reduced RIFA numbers on the main refuge/non-treated site and increased numbers of RIFA in the main refuge/treated site; this probably had an effect on invertebrate numbers and biomass in each of these areas. Invertebrate data was inconsistent with my hypothesis that invertebrate biomass and numbers would be greater in the treated areas than in the non-treated areas as the main refuge/non-treated site had more biomass than the other 2 sites. However, it also had the lowest RIFA abundance, suggesting that invertebrates are more abundant in areas with lower RIFA infestation. This supports my hypothesis that with fewer RIFA, invertebrate biomass will increase due to less RIFA predation on invertebrates.

I had to reject my hypotheses that there would be less RIFA in the treated area than non-treated area as the opposite was found. This was possibly due to a combination of the following factors: (1) more flooding on the non-treatment site which reduced RIFA numbers, (2) more RIFA in the treatment site due to rafting RIFA congregating on the higher elevation of this site, or (3) soil or vegetation differences between the sites which I did not evaluate.

When I looked at invertebrate numbers for 2016, the only significant difference between the 3 sites was the Austin County site had greater invertebrate numbers than did the main refuge/non-treated site. Considering the abundance of RIFA at the Austin County site was 11,065 (an average of 251.5 per site), the results were not consistent with my hypothesis that invertebrate numbers would be lower in areas that were not treated. I was not able to determine why the main refuge/non-treated site had significantly more invertebrate biomass than the Austin County site, but less number of invertebrates; however, it is possible that only the larger invertebrates survived the flooding in the non-treated man refuge site.

Although, I was not able to collect invertebrates after April 2017 (due to ending of my study), I was able to use April collection as an index for invertebrate recovery from the flood. Compared to April 2016, invertebrates in 2017 were greater in both numbers and biomass suggesting that invertebrates had recovered from the flooding event.

It is important to note that even though I expected more invertebrates in the treated area (based on my hypothesis), I did see the fewest RIFA in the main refuge/non-treated site (compared to the other 2 sites), but a greater biomass in the main refuge/non-treated area and not on the treated area as I had expected. However, the Austin County site supported my hypothesis as I found more RIFA and less invertebrate biomass in the Austin County site. In addition, there were less RIFA and more invertebrates in the main refuge/non-treated site which supports the results of Porter and Savignano (1990) when they found greater numbers of RIFA negatively affected invertebrates. What was more difficult to explain was that invertebrate numbers were greater on the Austin

County site, being that RIFA numbers also were greater on that site. Perhaps vegetation differences and less flooding at the Austin County site may have produced these results.

CHAPTER IV

THE EFFECT OF RIFA AND INVERTEBRATE ABUNDANCE ON BOBWHITE ABUNDANCE

Considerably literature can be found on the northern bobwhite (*Colinus virginianus*; hereafter bobwhite); its ecology, management, history, as well as the many potential causes of its decline. Among all those factors potentially contributing to the decline, the red imported fire ant (RIFA, *Solenopsis invicta*) has been proposed as one of the reasons for the decline of quail populations. Several studies of the impacts of RIFA on bobwhite chicks (Giuliano et al. 1996*a*, Mueller et al. 1999, Pedersen et al. 1996), nesting females (Wilson and Silvy 1988), and their overall population effects (Allen et al. 1995) can be found in the scientific literature. The effects of RIFA on invertebrate abundance (Porter and Savignano 1990) could reduce quail populations by reducing their important food source essential for nesting female quail and chicks (Brennan 2007). By reducing invertebrate abundances, females will not have the necessary nutrients to produce the normal number of eggs (about 12–15; www.wildlife.tamu.edu/quail/); nor will they have the resources to re-nest to sustain a healthy population. Chicks, on the other hand, need foods with high protein content in order to meet their fast-growing physical demands. Without the proper nutrients, chicks will not develop fast or well enough to overcome factor such as diseases, escape predation, extreme summer and winter temperatures, as well as other survival factors. It is recommended that newly-hatched chicks get about 28% protein in their diet during the first six weeks, thereafter, it drops to about 20% at 9 weeks of age (Lochmiller et al. 1993). The maximum egg production for laying female was found to be at 23% crude protein (Nestler et al. 1944, Giuliano et al. 1996*b*), protein at this level also was correlated with earlier and longer egg production. This is not to say that protein levels must be kept at this level; for optimum egg production, protein should be kept to at least 15% (Nestler et al.1944). Therefore, keeping a healthy invertebrate population is important to maintaining bobwhite populations as invertebrates are found to contain higher crude protein levels than plants (Wood et al. 1986, Giuliano et al. 1996*b*).

One pattern seen quite often in quail populations is the correlation of quail booms and busts with rainfall (Hernandez and Guthery 2012); quail tend to do well during wet seasons and seem to suffer during droughts. Positive precipitation correlations can be attributed to increased resources available during wet seasons that include increase in quality habitat, increase in seeds from grasses and forbs, and more importantly, it may be attributed to increase in invertebrate abundance. Lenhart et al. (2014) studying grasshoppers on a grassland, observed grasshopper density and species richness decreased much slower in watered plots than in control plots during drought conditions (Fig. 4.1). This observation further supports the hypothesis that bobwhites rely on invertebrate numbers to sustain their populations at high levels; furthermore, when invertebrate numbers are low it can be predicted that quail numbers will be low as well.

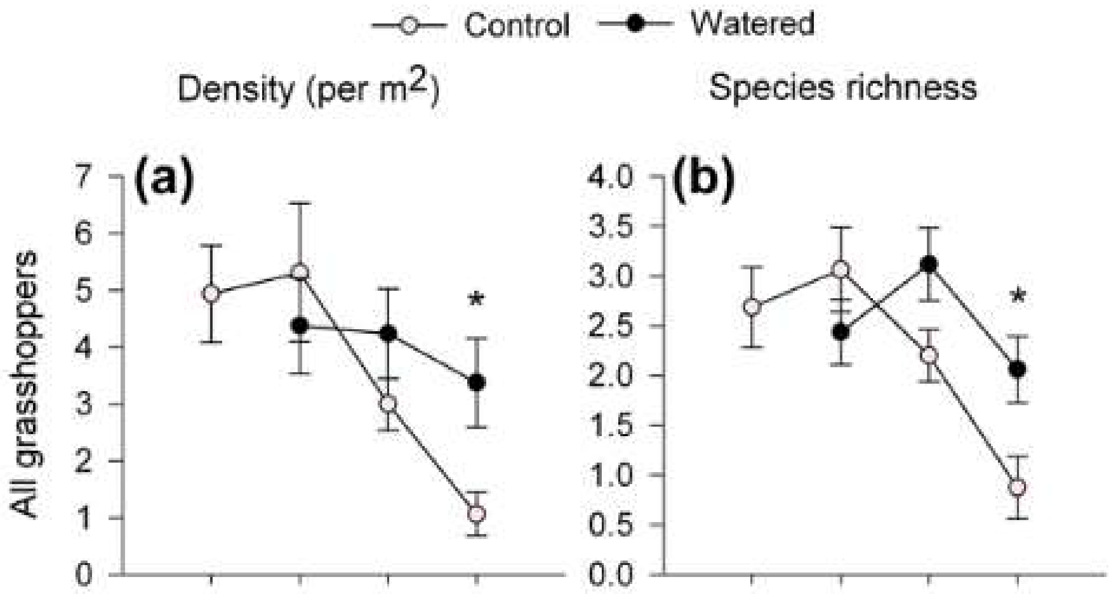


Figure 4.1: Grasshopper density and species richness (mean ± *SE*) of control and watered plots across months (May–August). Asterisks denote significant ($P < 0.05$; reprinted from Lenhart et al. 2014).

The juvenile to adult ratio is also an important parameter to measure when monitoring bobwhite population booms and busts as it provides a good index of reproduction (Guthery et al. 2002). When resources (food) are low, resulting in little reproduction to occur during a year, it is expected that the following year will have a low juvenile to adult ratio due to fewer number of bobwhite recruitment. In years when resources (food) are plentiful, the juvenile to adult ratio is usually expected to be higher the following year. Natural disasters (such as floods) can also have an influence in the juvenile to adult ratio, especially during nesting season which can reduce nesting success which will reduce juvenile recruitment into a population.

The objective for this portion of my study was to evaluate the effects of RIFA and invertebrate abundance on bobwhite abundance. My research hypothesis was that bobwhite abundance would be lower in areas with more RIFA and in areas with less invertebrate biomass and numbers.

STUDY AREA

Research was conducted at the Attwater Prairie Chicken National Wildlife Refuge (APCNWR) located about 100 km west of Houston, Texas in Colorado and Austin counties. Caldwell (2015) conducting research on my study site from 2014–2015, included only the main refuge located in Colorado County for his research. My study also included the Austin County portion of the refuge and was used as a control site for the effects of predator control on RIFA abundance. In theory, if mammalian predators are controlled, then there should be more rats, mice, and rabbit babies for RIFA to use as a food source. This mammalian food source (altricial young in nests) should be assessable to RIFA than arthropods that could avoid RIFA by moving, flying, or escaping up tall vegetation. Austin County had no predator control and was not treated for RIFA, whereas the main refuge (Colorado County) had predator control throughout and 75% of the area was treated (hereafter; main refuge/treated) and 25% was not treated (hereafter; main refuge/non-treated) for RIFA with Extinguish Plus®, a highly attractive ant control substance. RIFA treatment was applied at the APCNWR to allow increased survival and recruitment for the endangered Attwater's prairie chicken (*Tympanuchus cupido attwateri*). Since bobwhites share similar habitats with the prairie chickens, it allowed me the opportunity to determine if treatment with Extinguish Plus® also would increase bobwhite survival. Extinguish Plus® has an adulticide (Hydramethylnon), a long-lasting insect growth regulator (S)-mesophrene which works by sterilizing the queen to prevent further reproduction in the ant colony (www.extinguishfireants.com). Extinguish Plus® application is safe for horses and cattle, so it does not require any withdraw periods and it begins killing fire ants immediately after ingestion (www.extinguishfireants.com). Extinguish Plus® was applied yearly at 0.68 kg/0.40 ha to 3,035 ha of the 4,047-ha refuge. Annual aerial applications were conducted yearly in areas occupied by Attwater's prairie chickens; 75% of the refuge was treated for RIFA and 25% was not treated for RIFA (Terry Rossignol; Refuge Manager, APCNWR, personal communication). Areas treated with Extinguish Plus® were noted as treated areas and the areas not treated with Extinguish Plus® are noted as non-treated areas.

METHODS

Trapping sites were selected throughout the main refuge with 12 being in the treated sites and 20 being in the non-treated sites during 2016. In 2017, 15 traps were used in the treated area and 15 traps were used in the non-treated areas. No baiting or trapping was done at the Austin County portion of the refuge because it was separated from the rest of the refuge which made it impossible to trap both sites. Trapping sites were pre-baited at least once a week at previous quail sightings along APCNWR roads. Trapping began in mid- to late March to ensure the radio collar batteries would last through the nesting season (April to early October; www.wildlife.tamu.edu/quail/). Trapping took place from 25 March until 3 November 2016 and continued the next year (2017) from March 2017 through 1 June 2017 (the end of my project). Bobwhites were trapped once or twice a week using funnel traps baited with millet, cracked corn, milo, and sunflower, and wheat seeds placed in the middle of each trap. Male and female bobwhite trapped were leg banded and data was collected for weight, sex, age, and trap location. Age was categorized by either adult or juvenile using the greater primary covert feathers, buffy tips indicating a juvenile (hatch-year) quail (Petrides and Nestler 1943). In addition, females were fitted with a radio transmitter (150 MHz; Wildlife Materials, Carbondale, Illinois) and tracked with a 3-element Yagi antenna (Wildlife Materials, Carbondale, Illinois). A transmitter, weighing about 4% of their body weight (Mueller et al. 1988) was fitted around the neck of each female using a zip tie. All quail were then released at the site of capture. Females were tracked and located at least once a week and if they were seen in the same location for 4 days, I walked in on them to determine if they were nesting. If a mortality signal (indicated by fast, repetitive beeps) was detected, the radio was then located to determine cause of mortality. Females were monitored after the brood hatched to determine survival and movement data for females and broods. Relative abundance was calculated for each site (treated and non-treated) using t the Lincoln-Peterson mark-recapture method (Pierce et al. 2012).

RESULTS

For 2016 (March through November), I had 133 new captures and 171 recaptures for a total of 304 bobwhites. Of the 133 new captures, 30 (22.6%) were juveniles, 53 (39.8%) were hatch years, and 50 (37.6%) were adults. I calculated a 0.6:1 juvenile to adult ratio for the 2016 trapping season. For 2017 (up to 21 May), I had 28 new captures and 17 recaptures for a total of 35 captures; of the new captures 18 (64.3%) were juveniles and 10 (35.7%) were adults. I calculated a 1.8:1 juvenile to adult ratio for 2017 trapping. The total number of quail trapped from March 2016 through 21 May 2017, including recaptures, was 349. Bobwhite relative abundance was estimated at 87 (95% CI = 47–108) individuals using roads in June 2016 with 60 in the treated areas and 27 in the non-treated area. For the 2017 trapping efforts, the relative abundance was 53 (95% CI =36–70) with 43 in the treated area and 10 in the non-treated area.

DISCUSSION

Bobwhite seemed to have been negatively affected by the flooding which occurred on 18 April 2016. In the non-treated area of the refuge, where most of the flood occurred, I had lower trapping success compared to the rest of the refuge. In treated areas of the refuge (where less flooding occurred) within the Reichardt, Renz, and Corman pastures, more quail were observed and trapped than in areas that were more heavily flooded. I believe that in the treated areas of the refuge, bobwhites either drowned, displaced to other areas of the refuge, or left the refuge to adjoining areas. This probably explains the relatively low numbers of quail observed and trapped in the non-treated areas of the refuge compared to the treated areas.

In 2017, I observed less quail on roadside counts; however, quail trapped in 2017 had a 1.8 juveniles/adult ratio indicating above average nesting and brood survival for those quail that did survive the floods. Since the flood occurred during the nesting period, it is possible that most females were laying or incubating their first nests which were destroyed by the flood. However, because of the high percentage of juveniles trapped in 2017, it appears those females that were able to bring off a brood had sufficient resources to support larger broods. A 0.6 juvenile/adult ratio in 2016 indicated a high number of juvenile deaths or emigration out of the refuge after the flood or low reproduction during the 2015 nesting season. It also appears that RIFA abundance did not have an effect on bobwhites abundance as there were no differences found between the treated and non-treated areas of the main refuge. Thus, reduction of RIFA by flooding (killing and washing ants away) on the non-treated area reduced RIFA numbers to where they were more similar to RIFA numbers on the treated site.

Based on the 2016 trapping efforts, RIFA did not appear to influence bobwhite nesting success. Due to variables beyond my control, the treatment seemed to be ineffective in reducing RIFA in the treated area, contradicting what Caldwell (2015) found in his study. Based on my hypothesis, I expected bobwhite abundance to be greater in areas with less RIFA infestation; instead I found more RIFA in the treated area and bobwhite abundance was greater in that area as well, therefore I was not able to conclude that RIFA had an impact on bobwhite numbers. I believe more reliable results would have occurred if I had a more controlled setting as opposed to the many variables that may have influenced my study. Another important factor to consider is there was more treated (75%) than non-treated (25%) area, and of that treatment area, most of that land was favorable habitat for Attwater's prairie chicken. It also is possible that areas occupied by Attwater's prairie chickens also are more favorable for bobwhite.

Invertebrate abundance did not appear to have an observable effect on the bobwhite population. I was able to observe significantly greater invertebrate biomass in the main refuge/non-treated area, but the bobwhite abundance estimate was not consistent with my hypothesis. Based on my hypothesis, I expected more bobwhites in areas with greater invertebrate biomass and numbers; instead, I had lower bobwhite abundance estimate in the areas with more invertebrate biomass. The only significantly difference in the invertebrate numbers was that a greater number of invertebrates were collected at the Austin County site (I did not trap quail at this site) than in the main refuge/non-treated site. It is possible the flood may have impacted the invertebrate populations more on the main refuge/non-treated site than the Austin County site. An interaction between environmental variables such as floods, vegetation, and RIFA moving into treated areas complicated interpretation of my results.

CHAPTER V

CONCLUSION AND MANAGEMENT IMPLICATIONS

My research examined the effect of Extinguish Plus® treatment on RIFA and invertebrates and, as a result, their effects on the northern bobwhite. Based on my results, I can conclude the following: (1) Extinguish Plus® did not reduce RIFA abundance in the treatment area for 2016, (2) invertebrate biomass was greater at the main refuge/non-treated site where less RIFA were found, (3) invertebrate numbers were greater in the Austin County site where the most RIFA were found, and (4) bobwhite relative abundance was greater in the treated sites.

Heavy rain appeared to be the cause of the treatment not having an effect on RIFA abundance. Although, RIFA treatment was not effective, I can conclude that RIFA do affect invertebrate biomass as a high number of RIFA will result in less invertebrate biomass. I could not determine from my study the effects RIFA and/or invertebrates were having on bobwhites.

A number of factors could have contributed to my study not finding an effect of RIFA and/or invertebrates on bobwhite which can include; prescribed fires, soil infiltration variations, cattle grazing, some areas flooded more than others, and an uneven treatment area among others. A future study on RIFA, invertebrate, and bobwhite interactions would benefit by having a more controlled study site; one that will have less variation which can yield more accurate interpretation on these interactions.

Since invertebrates are an important food source for bobwhites, more invertebrate studies are needed to learn to what extent RIFA may be affecting invertebrates. Analyzing trends in invertebrate populations along with quail booms and busts would also bring a good understanding on how bobwhites rely on invertebrate abundances. Also, finding out if there is a threshold on the number of invertebrates a bobwhite population can thrive on would be important in determining the bobwhite-invertebrate interactions and how to further manage bobwhite and/or invertebrate populations to reverse the quail decline.

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